

# New Physics Effects on Higgs Production at $\gamma\gamma$ Colliders<sup>\*†</sup>

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**Abstract.** We study heavy physics effects on the Higgs production in  $\gamma\gamma$  fusion using the effective Lagrangian approach. We find that the effects coming from new physics may enhance the standard model predictions for the number of events expected in the final states  $\bar{b}b$ ,  $WW$ , and  $ZZ$  up to one order of magnitude, whereas the corresponding number of events for the final state  $\bar{t}t$  may be enhanced up to two orders of magnitude.

In the search of the nature and source of the electroweak symmetry breaking a decisive point will be the set in operation of the LHC and the next generation of linear  $e^+e^-$  collider (NLC). The NLC will permit us to use the old idea of Compton laser backscattering in order to reach a center of mass energy of  $\sqrt{s} = 200 - 500$  GeV [1] in the  $\gamma\gamma$  mode.

In particular, the  $\gamma\gamma$  colliders offer a great opportunity to study the dynamics of the elusive Higgs boson. If the standard model (SM) Higgs is detected through its dominant decay modes in  $e^+e^-$  or  $p\bar{p}$  collisions, then a  $\gamma\gamma$  collider will allow a direct measurement of its partial decay width into two photons. The  $H^\circ\gamma\gamma$  interaction is an one-loop prediction of the SM and all

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<sup>\*</sup>Work supported by CONACYT.

<sup>†</sup>To appear in the Proceeding of the *V Mexican Workshop of Particles and Fields*, Puebla, México, October 1995.

their extensions, in which all the contents of charged particles participates. Thus, a precise measurement of its decay width will permit us to discriminate between the SM and new physics predictions.

In the present work we study possible effects of new physics on the Higgs boson production in  $\gamma\gamma$  collisions within the context of the effective Lagrangian approach. The framework of effective Lagrangians, as a mean to parametrize physics beyond the SM in a model-independent manner, have been extensively discussed in the recent literature in both decoupling and nondecoupling cases [2]. In this work we consider the decoupling case [3], where the SM can be obtained as a low-energy limit of a weakly coupled renormalizable full theory. The heavy fields effects are parametrized by a series of high-dimensional nonrenormalizable operators, constructed out of the SM fields. These operators respect the SM symmetries [4], and because that, it is possible to establish the order of perturbative theory in which they may be generated in the full theory [5].

Since for  $m_{H^\circ} \leq 400$  GeV the total width of the Higgs boson is small in comparison with the energy of the photons beam, the number of  $H^\circ \rightarrow X$  expected events may be written as:

$$N = \left[ \frac{dL_{\gamma\gamma}}{dW_{\gamma\gamma}} \right]_{m_H} \frac{4\pi^2}{m_H^2} \Gamma(H^\circ \rightarrow \gamma\gamma) BR(H^\circ \rightarrow X) (1 + \lambda\tilde{\lambda}), \quad (1)$$

where  $BR(H^\circ \rightarrow X)$  is the branching ratio of the Higgs boson into the final state  $X$  ( $X = \bar{b}b, WW, ZZ, \bar{t}t$ ),  $\lambda$  and  $\tilde{\lambda}$  are the helicity states of the scattered photons,  $(dL_{\gamma\gamma}/dW_{\gamma\gamma})$  is the differential  $\gamma\gamma$  luminosity as a function of the two-photon invariant mass. Since the  $H^\circ\gamma\gamma$  interaction is generated at one-loop level by the dimension-four theory, a complete calculation requires to consider all the nonrenormalizable operators which contribute at this level in the full theory. All these contributions to the decay  $H^\circ \rightarrow \gamma\gamma$ , including the SM contribution, are suppressed by the loop factor  $(16\pi^2)^{-1}$ . Consequently, if the new physics scale  $\Lambda$  is not very far from the Fermi scale  $v = \sqrt{2}\langle\phi\rangle_0$ , the contributions of dimension eight operators, which may be generated at tree-level by the underlying physics, are dominant with respect to the contributions of the operators of dimension six [5-6]. Accordingly, the relevant effective Lagrangian for the Higgs boson production in  $\gamma\gamma$  fusion may be written as:

$$\begin{aligned} \mathcal{L}_{\text{eff}} = \mathcal{L}_0 &+ \frac{1}{\Lambda^2} [\alpha_{b\phi} O_{b\phi} + \alpha_{t\phi} O_{t\phi} + \alpha_\phi^{(1)} O_\phi^{(1)} + \alpha_\phi^{(3)} O_\phi^{(3)}] \\ &+ \frac{1}{\Lambda^4} [\alpha_{8,1} O_{8,1} + \alpha_{8,3} O_{8,3} + \alpha_{8,5} O_{8,5}], \end{aligned} \quad (2)$$

where  $\mathcal{L}_0$  is the SM Lagrangian and  $\alpha_i$  are unknown parameters; the operators of dimension eight and dimension six which induce the  $H^\circ\gamma\gamma$  and  $H^\circ q\bar{q}$  vertices at tree-level, are given in [6-7]. Using the Lagrangian (1) we obtain the following expressions for the partial decay widths,

$$\Gamma_{\text{eff}}(H^\circ \rightarrow \gamma\gamma) = \frac{\alpha^2 G_F m_H^3}{64\sqrt{2}\pi^3} \left| \sum_f Q_f^2 N_c F_0^f + F_0^b + \left(\frac{v}{\Lambda}\right)^4 F_{a8}^b \right|^2, \quad (3)$$

$$\Gamma_{\text{eff}}(H^\circ \rightarrow W^+W^-) = \left[ 1 + \frac{1}{4} \left(\frac{v}{\Lambda}\right)^2 (2\alpha_\phi^{(1)} - \alpha_\phi^{(3)}) \right]^2 \Gamma_{SM}(H^\circ \rightarrow W^+W^-), \quad (4)$$

$$\Gamma_{\text{eff}}(H^\circ \rightarrow ZZ) = \left[ 1 + \frac{1}{2} \left(\frac{v}{\Lambda}\right)^2 (\alpha_\phi^{(1)} + \alpha_\phi^{(3)}) \right]^2 \Gamma_{SM}(H^\circ \rightarrow ZZ), \quad (5)$$

$$\Gamma_{\text{eff}}(H^\circ \rightarrow \bar{q}q) = \left[ 1 - \frac{\sqrt{2}m_Z}{C_0 m_q} \left(\frac{v}{\Lambda}\right)^2 \alpha_{q\phi} \right]^2 \Gamma_{SM}(H^\circ \rightarrow \bar{q}q), \quad (6)$$

where  $q$  stands for the  $b$  and  $t$  quarks,  $Q_f$  is the electric charge of the fermions,  $N_c$  is 3 for quarks and 1 for leptons,  $C_0 = m_Z \sqrt{\sqrt{2}G_F}$ . The parametric functions  $F_0^f$  and  $F_0^b$  associated to fermions and  $W$  boson loops, respectively, are given in Ref.[8],  $F_{a8}^b$  is given in [7].

In Fig. 1-2 we display the number of expected events as a function of the Higgs boson mass for the final states  $\bar{b}b$  and  $\bar{t}t$ . The corresponding figures for the final states  $WW$  and  $ZZ$  are shown in [7], they show the same behaviour as the  $\bar{b}b$  case. We have taken all the coefficients of the nonrenormalizable interactions as  $|\alpha_i| = 1$  and the new physics scale as  $\Lambda = 1$  TeV. We consider a center of mass energy of the  $e^+e^-$  collider equal to 500 GeV. The luminosity of the  $e^+e^-$  beam is taken equal to  $20\text{fb}^{-1}$ . Furthermore, we have considered the theoretical limit  $\lambda\tilde{\lambda} = 1$ .

We present only the two extreme scenarios corresponding to a maximum and a minimum number of events for the total contribution, which includes effective interactions in all the vertices involved. We have checked that for  $\Lambda \geq 3$  TeV, the heavy physics effects decouple from the SM predictions. In the scenario with a maximum number of events we can appreciate an enhancement of almost one order of magnitude, with respect to the SM predictions, for the final state  $\bar{b}b$ ,  $WW$  and  $ZZ$ , while for the  $\bar{t}t$  channel the enhancement may be up to two orders of magnitude [7]. In the less favorable scenario the  $\bar{b}b$  final state is suppressed by one order of magnitude with

respect to the SM prediction, while in the  $\bar{t}t$  final state subsist a remarkable enhancement with respect to the SM predictions.

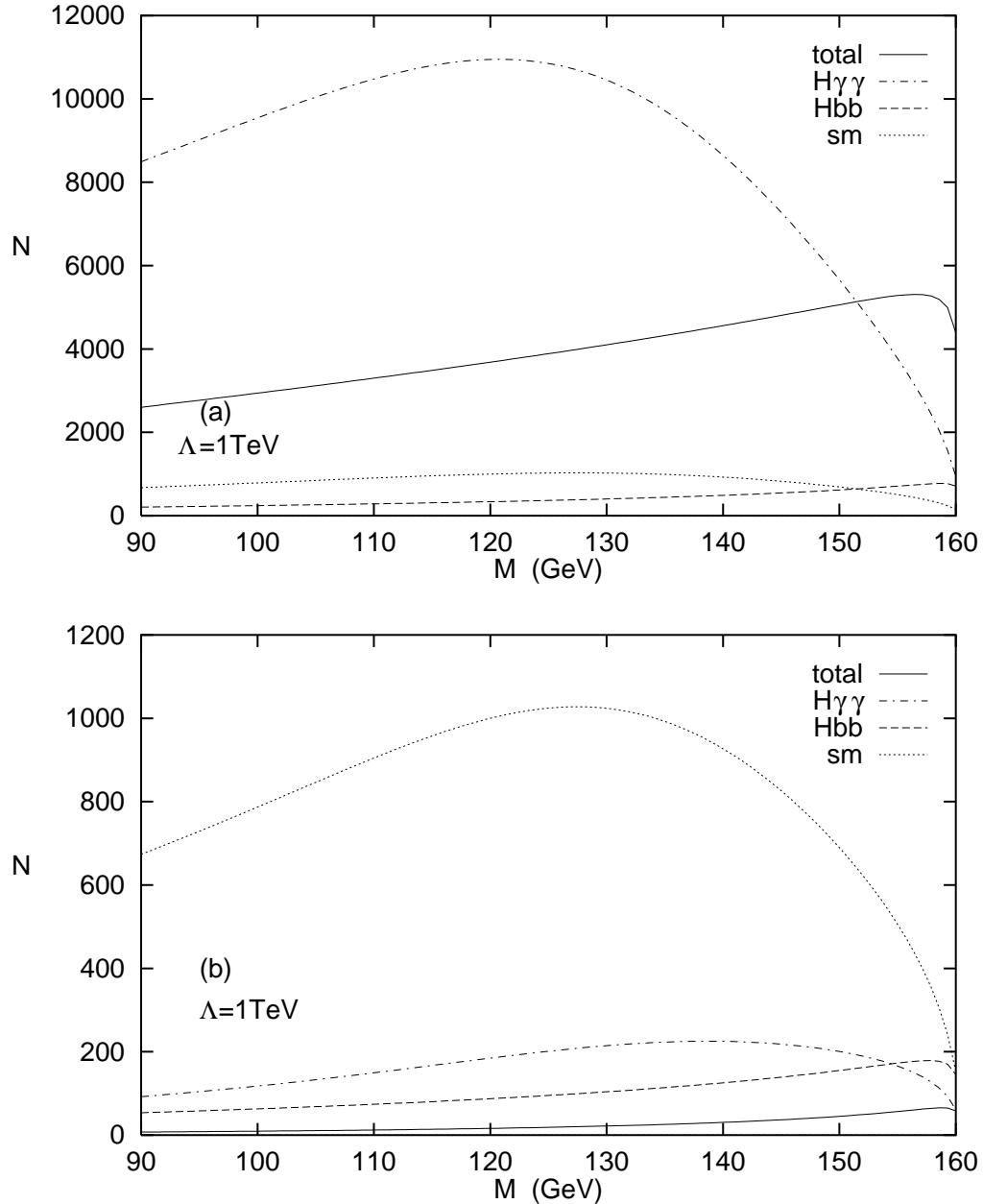


Fig.1. Number of events expected for the  $\bar{b}b$  final state as a function of the Higgs boson mass and  $\Lambda = 1$  TeV, for the scenarios with a maximum (a) and minimum (b) number of events.

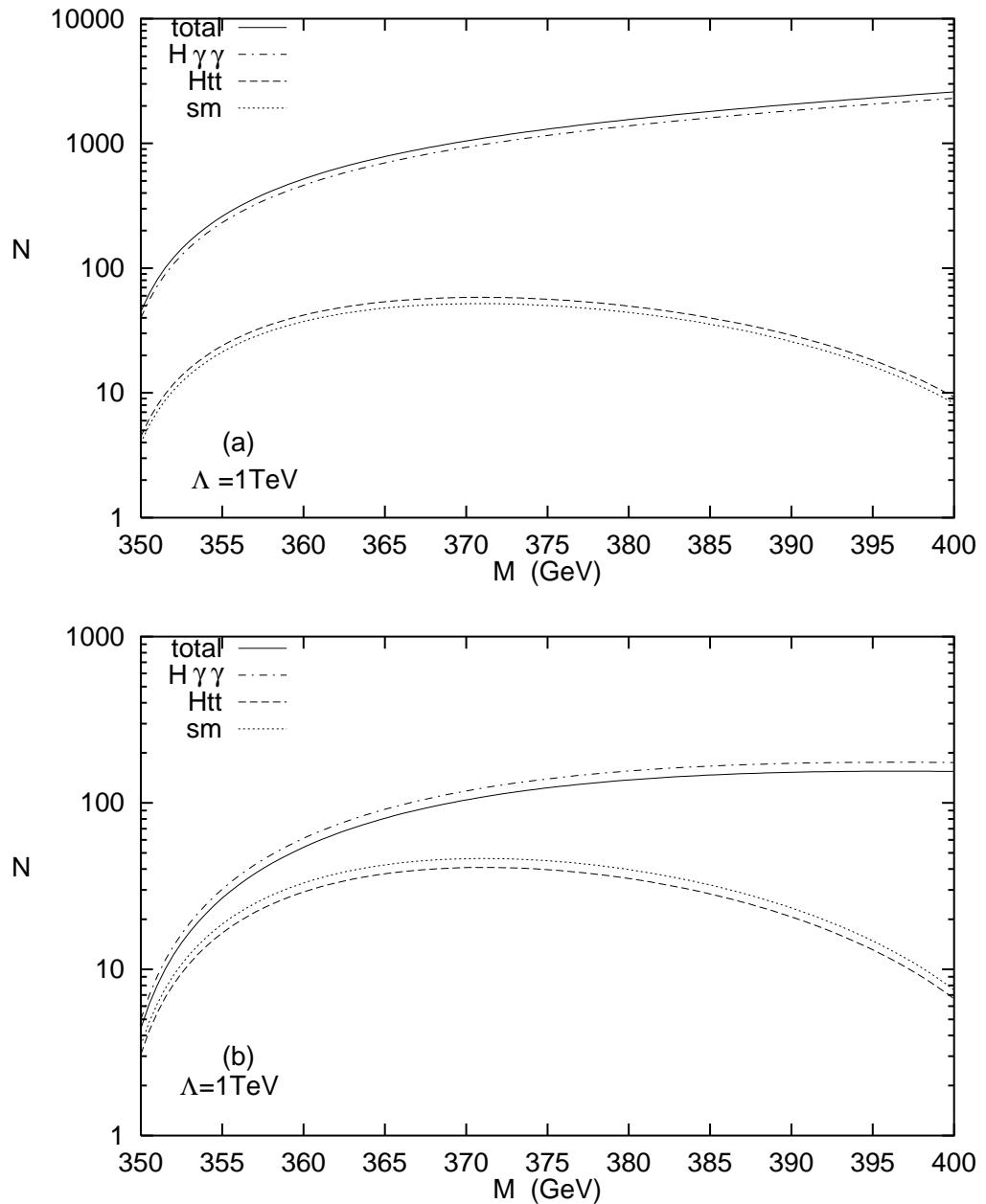


Fig. 2. Number of events expected for the  $\bar{t}t$  final state as a function of the Higgs boson mass and  $\Lambda = 1 \text{ TeV}$ , for the scenarios with a maximum (a) and minimum (b) number of events.

In conclusion, the Higgs boson production through  $\gamma\gamma$  fusion results in a highly sensitive mechanism to detect physics beyond the SM. Furthermore, we expect that the enhancement induced by new physics on the signal is not hidden by the corresponding effects on the background.<sup>‡</sup>

## References

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<sup>‡</sup>This issue is discussed more extensively in [7].